

# SALIENT TRIGGER PARAMETERS FOR INDUCING LOCK-ON IN GALLIUM ARSENIDE PHOTOCONDUCTIVE SEMICONDUCTOR SWITCHES

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## Abstract

To date, many of the investigations into lock-on mode Gallium Arsenide (GaAs) switching have centered on the use of the readily obtainable fundamental (1,064 nm) and second harmonic (532 nm) radiation from Nd:YAG laser systems. For the current work, a tunable (710 - 910 nm) Titanium Sapphire (Ti:Sapphire) laser system was used to provide trigger energy at the largely unexplored wavelengths about the bandedge of GaAs (873 nm). The minimum trigger energy required to induce lock-on was determined as a function of wavelength, beam intensity, and beam spot size. These parameters were measured for two switch lengths and two contact designs. Data will be presented which indicates that the minimum energy required to induce lock-on in GaAs PCSS devices is strongly dependent on all of the measured parameters.

## Introduction

Photoconductive Semiconductor Switch (PCSS) devices have shown great promise for use in a wide variety of applications of interest to the United States Air Force. In particular, GaAs as a PCSS material is being actively investigated.

It has been well documented in the literature that GaAs as a PCSS exhibits an optical gain process known as "lock-on" [1]. Because GaAs exhibits this characteristic and is capable of switching high voltages ( $> 100$  kV) with very fast risetimes ( $< 500$  ps) these devices bring to light the prospect of greatly reducing the laser system requirements in many PCSS based systems.

In this publication, the authors have concentrated on two salient trigger parameters related to GaAs PCSS device performance which may significantly reduce the amount of laser energy required. These parameters are trigger light wavelength and spatial distribution as they relate to switching efficiency. Here, maximum switching efficiency is defined as producing lock-on mode switching with a minimum amount of trigger light energy. In addition, a better understanding of these parameters has shed some light on the fundamental switching parameters involved in this phenomenon.

The primary parameter investigated was switching efficiency as a function of trigger light wavelength. During this investigation, the effect of trigger wavelengths in the range of 850 nm (1.44 eV) to 900 nm (1.37 eV) was examined. This range of wavelengths

was chosen to determine switching efficiency in the region of the bandedge at room temperature (See Figure 1).

The second parameter investigated was switching efficiency as a function of trigger light spatial distribution. This parameter was chosen because previous investigations have indicated that the lock-on effect may have processes in common with the streamer model of gaseous breakdown [2]. As such, it has been proposed that a focused spot of trigger energy may produce more efficient switching than a less intense spot of the same energy. Preliminary experiments performed at Sandia National Laboratory (SNLA) have indicated that a relatively small beam spot size may increase switching efficiency [3]. During this investigation, the authors determined switching efficiency as a function of trigger light intensity and beam spot size.

## Experimental Setup

The experimental setup can be simplified into three fundamental systems; the laser/optical system, the pulsed power generation system, and the transmission line test fixture system. The laser/optical system remained constant throughout the duration of the experiment. Two pulsed power systems and two transmission line test fixture systems were employed for the experiments; one each for the 0.25 cm switches and one each for the 1.0 cm switches (See Figures 2a and 2b). Each of these systems is discussed below.

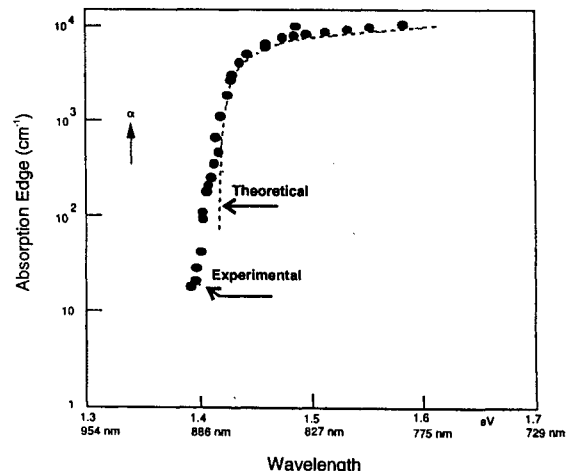


Figure 1. Absorption for GaAs.

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1. REPORT DATE <b>JUN 1993</b>		2. REPORT TYPE <b>N/A</b>		3. DATES COVERED <b>-</b>	
4. TITLE AND SUBTITLE <b>Salient Trigger Parameters For Inducing Lock-On In Gallium Arsenide Photoconductive Semiconductor Switches</b>				5a. CONTRACT NUMBER	
				5b. GRANT NUMBER	
				5c. PROGRAM ELEMENT NUMBER	
6. AUTHOR(S)				5d. PROJECT NUMBER	
				5e. TASK NUMBER	
				5f. WORK UNIT NUMBER	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) <b>US Air Force Phillips Laboratory Kirtland AFB, NM 87185</b>				8. PERFORMING ORGANIZATION REPORT NUMBER	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)				10. SPONSOR/MONITOR'S ACRONYM(S)	
				11. SPONSOR/MONITOR'S REPORT NUMBER(S)	
12. DISTRIBUTION/AVAILABILITY STATEMENT <b>Approved for public release, distribution unlimited</b>					
13. SUPPLEMENTARY NOTES <b>See also ADM002371. 2013 IEEE Pulsed Power Conference, Digest of Technical Papers 1976-2013, and Abstracts of the 2013 IEEE International Conference on Plasma Science. Held in San Francisco, CA on 16-21 June 2013. U.S. Government or Federal Purpose Rights License.</b>					
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15. SUBJECT TERMS					
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT <b>SAR</b>	18. NUMBER OF PAGES <b>4</b>	19a. NAME OF RESPONSIBLE PERSON
a. REPORT <b>unclassified</b>	b. ABSTRACT <b>unclassified</b>	c. THIS PAGE <b>unclassified</b>			

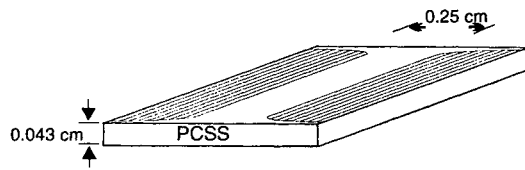


Figure 2a. The 0.25 cm switch.

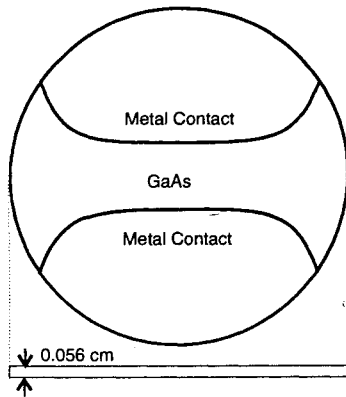


Figure 2b. The 1.0 cm switch on a 2" wafer.

### Laser/Optical System

The laser trigger energy was produced by a tunable STI Optronics HRL-1 Titanium Sapphire (Ti:Sapphire) laser which was pumped using the frequency doubled 532 nm output of a Spectra Physics Quanta Ray model GCR-16S Nd:YAG laser. The HRL-1 is capable of producing more than 1 mJ of output energy between 710 nm and 910 nm (3 - 5 ns pulse width). A Burleigh Pulsed Wavemeter was used to verify the output wavelength of the HRL-1 and a Gentec model ED-100 energy sensor was used to monitor the energy delivered to the switch.

The 1 mm diameter output beam of the HRL-1 laser was spatially filtered and expanded using a two lens system with pin hole to provide relatively uniform illumination of the switch surface. The beam was then attenuated to the appropriate energy level using metallic coated neutral density filters before being delivered to the switch. The entire laser/optical system is shown in Figure 3.

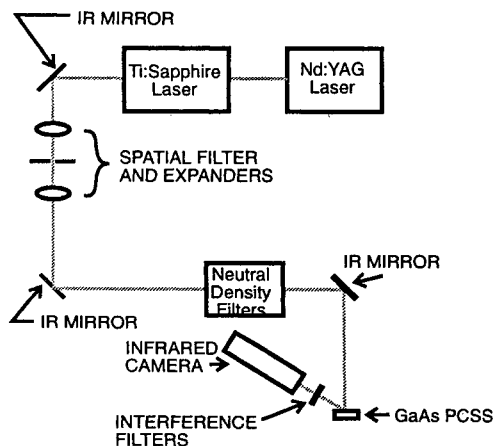


Figure 3. The laser/optics system.

### Pulsed Power Sources

The pulsed power source used to provide voltage for the 0.25 cm switch tests is shown in Figure 4. This source is capable of providing between 0 and 5 kV to the switch with a 1 ms charge time. A charge waveform is given in Figure 5. During the tests of the 0.25 cm switches, the voltage was maintained at 4.2 kV to give a constant average switch field of 16.8 kV/cm.

The pulsed power source used to provide voltage for the 1.0 cm switch tests is shown in Figure 6. The source is a 2 stage Marx generator with an 8 stage peaking capacitor system and variable lumped series inductance. This source is capable of providing between 20 kV and 200 kV to the 1.0 cm switch test fixture with a  $1-\cos(\omega t)$  waveshape and a 180 ns risetime. The charge voltage is adjustable by means of varying the Marx charge voltage and the pick off point in the peaking capacitor stack. The charging

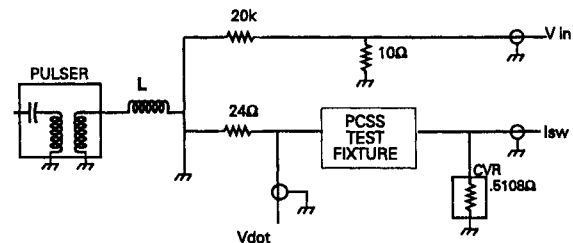


Figure 4. The pulsed power network for 0.25 cm gap switches.

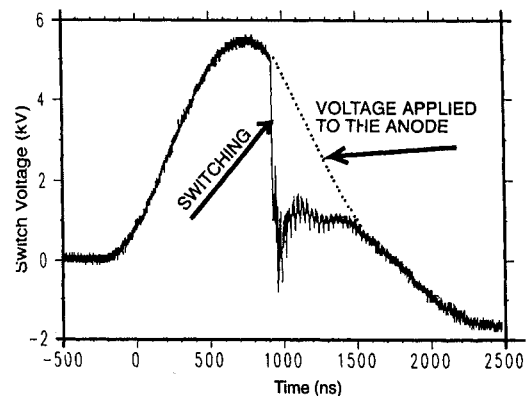


Figure 5. Charge waveform for 0.25 cm gap switches.

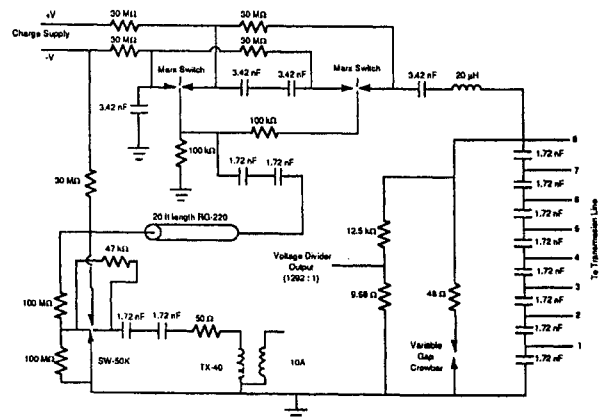


Figure 6. The pulsed power network for 1.0 cm gap switches.

## EXPERIMENTAL PROCEDURE AND DATA

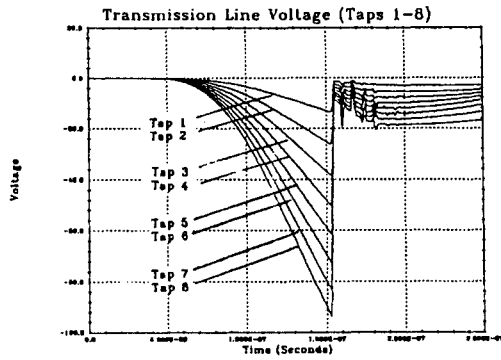


Figure 7. Charge waveform for 1.0 cm gap switches.

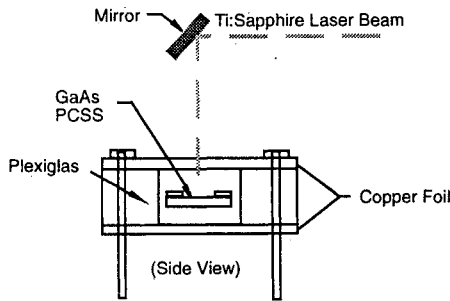


Figure 8. The transmission line test fixture for 0.25 cm switches.

waveform risetime is adjustable by varying the lumped series inductance. Typical charging waveforms are given as Figure 7. During the tests, the 1.0 cm switches were tested at 16.8 kV/cm only.

### Transmission Line Test Fixtures

The fixture used to test the 0.25 cm switches is shown in Figure 8. The fixture is essentially a 50  $\Omega$  transmission line switched by the PCSS into a 50  $\Omega$  load. The PCSS is soldered to the transmission line and load using copper strips and is immersed in Fluorinert for dielectric protection. The transmission line provides the fast risetime into the load and the source provides the slow decay. Mounted to the transmission line are a fast voltage probe and a fast current probe.

The fixture used to test the 1.0 cm switches is shown in Figure 9. The test fixture is a 110  $\Omega$  rectangular geometry coaxial transmission line with a 7 ns one way transit time. SF<sub>6</sub> at 40 psig is used as the dielectric. The PCSS is mounted at the input end of the transmission line between the inner and outer conductors. A fast risetime (< 100 ps) capacitive probe is mounted to the outer conductor of the transmission line near the PCSS to measure the switch risetime and switched voltage amplitude. The entire transmission line is contained in a 10" inner diameter steel tube pressure vessel with steel end plates. The end plates have windows to allow entry of the laser beam. A resistive voltage divider is mounted to the pressure vessel which monitors the charging voltage delivered to the test fixture.

The same test procedure was used for both the 0.25 cm and 1.0 cm switches. Testing started by delivering 100  $\mu$ J of 850 nm trigger energy to the switch in a beam size equal to one third of the switch gap length with a 16.8 kV/cm average switch field. The beam was initially located at the center of the switch. Upon determination of the minimum energy required to produce switching (this included finding the best location for the beam), the wavelength was increased and the minimum trigger energy was determined beginning with the previously determined minimum trigger energy level. This procedure was repeated with the trigger wavelength being increased to 900 nm at a constant switch field level. Upon completion of the testing at 900 nm, the laser was adjusted to the optimum trigger wavelength and the beam diameter was varied while the minimum required trigger energy was monitored. Both the 1.0 cm switches and the 0.25 cm switches were tested at 16.8 kV/cm only.

The minimum trigger energy as a function of wavelength can be seen in Figures 10 and 11. The minimum trigger energy as a function of beam diameter can be seen in Figures 12 and 13. As can be seen from the data, minimum trigger energy occurred at or near 880 nm in all cases. The minimum trigger energies required at 850 nm and 900 nm were 4.6 and 6.2 times that required at 880 nm respectively. In all cases, the minimum required trigger energy was less with a large beam size than with a small beam size.

## DISCUSSION

Above the bandgap energy level, the majority of the trigger energy is absorbed at the surface of the GaAs while at longer wavelengths significant laser light is transmitted through the switch (See Figure 1 [5]). The minimum trigger energy did not occur at the zero field band gap edge measured to be 873 nm but occurred below the band gap at 880 nm. According to the Franz-Keldysh effect, the band gap edge is shifted toward longer wavelengths upon the application of high electric field intensities. K. H. Schoenbach [4] measured the effect on GaAs PCSS devices. The results indicated a 6-8 nm shift (towards lower energy levels) in the bandedge absorption curve. This results in the bandedge occurring at 879-881 nm, which is consistent with

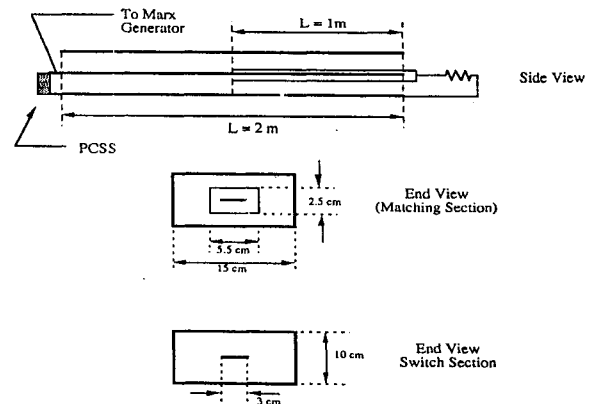


Figure 9. The transmission line Test fixture for 1.0 cm switches.

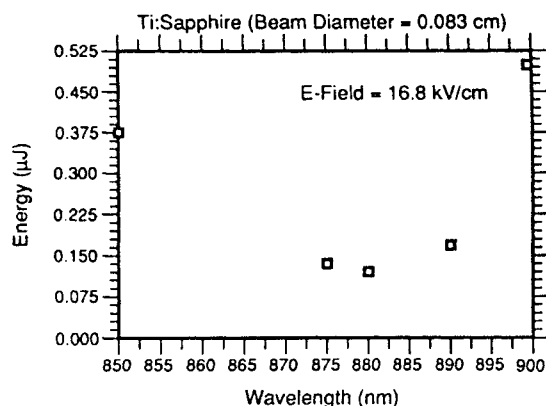


Figure 10. Graph of minimum trigger energy vs laser wavelength for 0.25 cm switches.

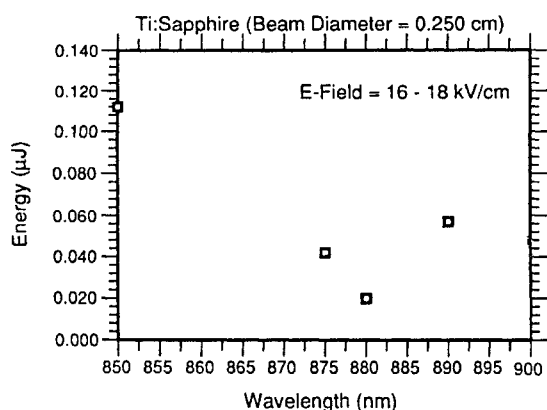


Figure 11. Graph of minimum trigger energy vs laser wavelength 1.0 cm switches.

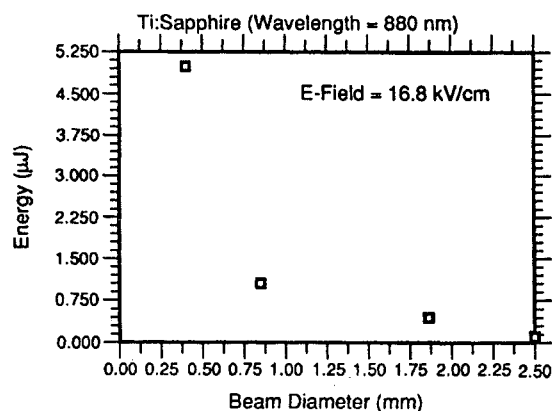


Figure 12. Graph of minimum trigger energy vs beam diameter 0.25 cm switches.

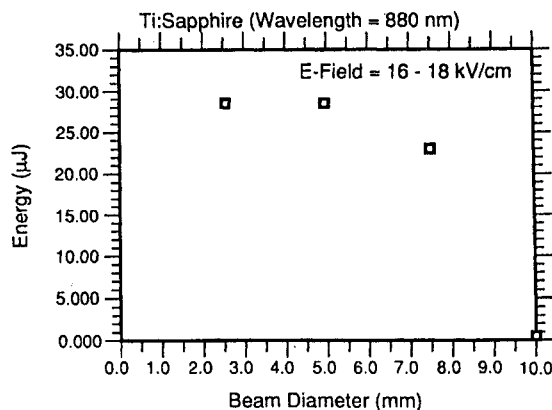


Figure 13. Graph of minimum trigger energy vs beam diameter 1.0 cm switches.

the minimum trigger energy wavelengths measured in these experiments. This indicates that the minimum trigger energy occurs in the region of the bandgap where the maximum depth of switch material is illuminated while minimizing transmitted light. It was also found that less total trigger energy was required to induce lock-on when the laser light illuminated the entire active switching medium (low energy density) rather than a small region (high energy density).

### CONCLUSIONS

The minimum trigger energy to induce lock-on occurs when the maximum volume of switch material is illuminated (depth \* area). This may be achieved by triggering the switch with light energy corresponding to the bandgap edge. The Franz-Keldysh [5] effect should be taken into account when determining the proper wavelength.

Future work will center around greater field levels, novel contact geometries and different switch gap lengths.

### ACKNOWLEDGMENTS

We would like to thank Fred Zutavern, Guillermo Loubriel, and Dan McLaughlin of SNLA for contributing their time and resources to this experiment. The low voltage pulsed power source and 0.25 cm gap switches were provided by SNLA.

We would also like to thank Dan O'Shea of Phillips Laboratory for his assistance in supplying absorption data for the 1.0 cm switches.

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